Charge asymmetry in the photonic production of charmed mesons

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Charge asymmetries for the charm meson production (D^{*+}–D^{*-}, D^{*0}–$\bar{D}^{*0}$ and D_s^+–$\bar{D}_s^-$) have been estimated for the COMPASS kinematic conditions in the framework of perturbative recombination model. Mass corrections have been taken into account in the calculations. The large asymmetry for D_s^+–$\bar{D}_s^-$ production has been predicted.

1. INTRODUCTION

A production of hadrons is a good testbed for the research of quark and gluon interactions at the distance of color confinement.

On the one hand the intermediate value of c-quark mass complicates the process description in the QCD frame work, on the other hand this quark mass value allows us to research heavy quark interaction at the distances, which are larger than there Compton wave length.

The production asymmetry of charmed particles and antiparticles has been observed in many high-energy experiment. For the first time such asymmetry had been discovered in the charm hadronic production [1]. The asymmetry value in that process depends on the quark structure of initial hadrons, and can be naturally explained by taking into account the interaction with the hadronic remnant [2].

It is more amazing that a such charge asymmetry exists in the charm photoproduction in the photon fragmentation region [3–5]. E691 [3] and E687 [5] Collaborations observed the statistically significant asymmetry value for $D^+ - D^-$, $D^0 - \bar{D}^0$ and $D^{*+} - D^{*-}$ yields. This fact speaks well for the essential role of valence quarks of the initial hadron even in the region of photon fragmentation at their photon energy.

The observed asymmetry cannot be explained in the frame work of pQCD and factorization

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theorem for the inclusive D-meson spectra. It is well known, that in the leading order on α_s of perturbative theory D- and $\bar{D}$-meson one gets identical spectra. At NLO calculations [6] it is appeared a small asymmetry due to the quark-photon interaction:

$$\gamma + q \to c + \bar{c} + q. \tag{1}$$

Indeed, the NLO-calculations for the photon energy of $E_\gamma = 200$ GeV leads to the asymmetry value which is smaller than the experimental one by the order of magnitude. Thus, the hard production of $c\bar{c}$-pair followed by the fragmentation into hadrons can not describe a such asymmetry. It is worth to note that this situation is analogous to the situation with weak decays of D-meson, where spectator mechanism can not explain lifetime difference between charged and neutral D-meson. So, one need to take into account the interaction with a charmless component of meson, as well the interference terms.

Besides of an experimentally observed asymmetry there is another problem in using the factorization approach to estimate D-meson production cross section. The thing is that at small transverse momenta one can not represent D-meson production as $c\bar{c}$-pair production with further c-quark fragmentation into D-meson, because there is an interference between the light quark produced during c-quark fragmentation and that from a hadronic remnant. That taking into account the interference contribution one could determine the region, where the factorization approach is valid.

We have tried to explain in [7] the both discussed effects (the asymmetry and the interference) by including into perturbative calculation in addition to heavy quarks the light ones needed to obtain a hadron with desired quantum numbers. In so doing the light quark has a mass $m_q \sim \Lambda_{\rm QCD} \sim 300$ MeV, which plays a role of an infrared cut-off. However, the inclusion of the light one essentially complicates calculations. For example, the production process in gluon-gluon interaction is described by 36 diagrams of $O(\alpha_s^4)$ order, the production process in photon-photon interaction is described by 24 diagrams of $O(\alpha\alpha_s^3)$ order.

The principal features of the discussed model are as follows:

1. At large transverse momenta the model predictions coincide with the predictions of the fragmentation mechanism. The cross section dependence on D-meson transverse momentum $P_\perp^D$ have the standard factorized form:

$$\frac{d\sigma(ij \to D + X)}{dp_\perp^D} = \int \frac{d\sigma(ij \to c\bar{c})}{dp_\perp^c} f_{c\to D}(z_D)\delta\left(z_D - \frac{p_\perp^D}{p_\perp^c}\right) dz_D dp_\perp^c \tag{2}$$

were i and j are interacting partons, $p^c_\perp$ is a transverse momentum of c-quark, and $d\sigma(ij \to c\bar{c})/dp^\perp_c$ is the production cross section of $c\bar{c}$-pair in the leading order.

2. In small transverse momenta region there is appeared a new contribution that leads to power corrections $\dfrac{m_c^2}{p_T^6}$. This contribution violates the factorized equation (2).
3. At small p_T and large longitudinal momenta (i.e. at large x) it is appeared a strong interference and the production cross section can not be described by (2).

Note that the fragmentation function $f_{c\to D}(z_D)$ in (2) is calculated perturbatively in the frame work of the discussed model and has the form:

$$f_{c\to D^{(*)}} = \frac{\alpha_s^2\langle O(^3S_1)\rangle}{m_q^2 m_c} I^{D^{(*)}}(z_D, r), \tag{3}$$

where $r = m_q/m_c$ and I is a function on z_D and r. Let us to note, that the evaluated function is close in form to Peterson fragmentation function [10]. [1]

Variables $\langle O(^3S_1)\rangle$ and $\langle (O^1S_0)\rangle$ in the relativistic limit correspond to a wave function squared at the coordinate origin. In the discussed model these variables are considered as free parameters. The values of $\langle O(^3S_1)\rangle$ and $\langle (O^1S_0)\rangle$ have been chosen to satisfy the normalization condition

$$W_{c\to D^{(*)}} = \int f_{c\to D^{(*)}}\, dz_D, \tag{4}$$

where $W_{c\to D^{(*)}}$ is the probability of fragmentation $c \to D^{(*)}$ taken from the experimental date on e^+e^--annihilation. As it is seen from (3) and (4), the values of m_q, α_s and $\langle O(^3S_1)\rangle$ (or $\langle O(^1S_0)\rangle$) are correlated to each other. For example for $m_q = 0.3$ GeV and $\alpha_s = 0.3$ GeV one gets

$$\langle O(^3S_1)\rangle \simeq \langle O(^1S_1)\rangle = 0.25\,\mathrm{GeV}^3.$$

These values allow to describe the experimental data on photo- and electroproduction at HERA collider [8].

It is worth to emphasize the role of the following process for the charm production:

$$\gamma + q \to D^{(*)}(\bar{c}q) + c. \tag{5}$$

[1] It is important to stress, that the common belief in nonperturbative nature of Peterson fragmentation function is not valid. The dependence on z in that function is caused by the heavy quark propagator. It had been shown in the original work [10], that to obtain this dependence one need to take into account only the right pole of propagator $1/(E - E')$ in the infinite reference frame.

Due to $q \leftrightarrow \bar{q}$ asymmetry in the structure functions of the initial hadrons the process (5) leads to a charge asymmetry in the $D^{(*)}$-meson yields. This process dominates at low energies and large values of Feynman variable $x_F = \frac{2p_L^D}{\sqrt{s}}$ where p_L^D is a longitudinal momentum of D-meson. At high energies at small x_F the contribution of such process is negligible. At kinematic conditions of HERA collider the process (5) contributes only several percents into the total cross section value, which is within experimental errors [7].

Following [9] we refer the process (5) as a perturbative recombination. The detailed analysis of the perturbative recombination reveals that the cross section behavior depends rather weakly on a light quark mass. The analytic calculations in the limit as $x_q \to 0$, where x_q is a momentum fraction of D-meson carried by the light quark, exhibit several interesting features of the process (5). That, accordingly to the results of [9], in the initial light quark direction ($\theta = 0$)

$$\left.\frac{d\sigma(\gamma + q \to (\bar{c}q) + c)}{d\sigma(\gamma + q \to c + \bar{c})}\right|_{\theta=0} \simeq \frac{256\pi}{81}\alpha_s \tag{6}$$

for both $(\bar{c}q)(^1s_0)$ and $(\bar{c}q)(^3s_1)$-states. One can see that in spite of an additional power of α_s the cross section value of the process (5) is comparable to the cross section value of the photon-gluon fusion. In the photon direction ($\Theta = \pi$) the production cross section is suppressed by additional factors of m_c^2/s [9]:

$$\left.\frac{d\sigma(\gamma + q \to (\bar{c}q) + c)}{d\sigma(\gamma + g \to \bar{c} + c)}\right|_{\theta=\pi} \simeq \begin{array}{l} \frac{256\pi}{81}\alpha_s \frac{m_c^6}{s^3} \ \text{for} \ {}^1S_0 \\ \\ \frac{256\pi}{81}\alpha_s \frac{m_c^2}{s} \ \text{for} \ {}^3S_1 \end{array} . \tag{7}$$

At large transverse momenta $p_\perp$ the cross section is suppressed by an additional factor of $m_c^2/p_\perp^2$ and falls of like $\dfrac{1}{p_\perp^6}$.

2. CALCULATION RESULTS

The cross section dependence on scattering angle for perturbative recombination is shown in Fig. 1for both vector and pseudoscalar states of $(\bar{c}q)$-system. For the sake of comparison the cross section behaviour is presented for the case of limit $x_q \to 0$ [9], as well as for the nonzero mass of light quark $m_q = 0.3$ GeV. One can see that at low energies the production cross section for pseudoscalar $(\bar{c}q)$-state in the photon direction ($\Theta = \pi$) is more then 10 times less than the production cross section of vector $(\bar{c}q)$-state. These calculation results become similar to each other at high energy and in the limit as $m_q \to 0$ (see Fig. 2). It is seen from these figures that the $(\bar{c}q)$-state production in the backward direction (in the photon direction) is suppressed in comparison

with the production in the forward direction (the factor of $m^2(s)$). As a rule at fixed target facilities the research of production is only possible in the photon direction. Therefore the contribution of perturbative recombination must be small. In addition to that the charge asymmetry should decrease with the increasing of beam energy. On the other hand there is no suppression at the production yield alongside to hadron direction (see eq. (6)). It leads to energy-independent charge asymmetry.

Before proceeding further, it is necessary to remove perplexity which could appear after comparing the predictions (6) and (7) with the results following from Fig. 2. Indeed one can see from Fig. 2 that the yields of vector and pseudoscalar mesons are practically identical in the backward production ($\Theta \simeq \pi$), while the vector mesons dominate in forward production ($\Theta \simeq 0$). However, these results contradict (6) and (7). The point is that the mathematical limits of the cross section values evaluated in [9] are correct. But these quantities have no physical meaning. As it is shown in our study the production cross sections for vector and pseudoscalar states are practically the same in the kinematical region $-0.99 < \cos\Theta < -0.8$, whereas the limit regime establishes only at $\cos\Theta < -0.99$. The integral cross section value in the kinematical region $-1 < \cos\Theta < -0.99$ is negligible in comparison with the integral cross section in the kinematic region $-0.99 < \cos\Theta < -0.8$. It was revealed also that in the forward production at $0.9 < \cos\Theta < 0.999$ the vector mesons dominate: while at $\cos\Theta = 1$ the ratio between the vector meson production and the pseudoscalar production equals to 1, but at $\cos\Theta = 0.999$ that ratio is about 7. The contributions from region $0.999 < \cos\Theta < 1$, as well as from region $-1 < \cos\Theta < -0.99$ into the total cross section are negligible. Now it is clear that the predictions (6) and (7) are beyond both the model accuracy and the experimental potentialities. Therefore the physically reasonable predictions at large s are as follows:

$$\left.\frac{d\sigma(\gamma + q \to (\bar{c}q)(^3s_1) + c)}{d\sigma(\gamma + q \to (\bar{c}q)(^1s_0) + c)}\right|_{\theta\simeq 0,\, s\gg m_c^2} \gg 1, \;\; d\sigma(\gamma + q \to (\bar{c}q) + c)|_{\theta\simeq 0,\, s\gg m_c^2} \sim \frac{1}{s}, \tag{8}$$

$$\left.\frac{d\sigma(\gamma + q \to (\bar{c}q)(^3s_1) + c)}{d\sigma(\gamma + q \to (\bar{c}q)(^1s_0) + c)}\right|_{\theta\simeq \pi,\, s\gg m_c^2} \simeq 1, \;\; d\sigma(\gamma + q \to (\bar{c}q) + c)|_{\theta\simeq \pi,\, s\gg m_c^2} \sim \frac{1}{s^4}. \tag{9}$$

Let us consider in detail the both perturbative recombination and photon-gluon fusion. We restrict ourself to the calculation of production asymmetry for D^*-mesons, because we expect the suppression of the D-meson production in the photon direction in comparison with the D^*-meson production.

For the numerical analysis we choose the kinematical cuts of COMPASS experiment, t.e.: the averaged energy of the muon beam is 160 GeV, the photon virtuality $Q^2 < 1$ GeV^2; $x_F > 0.2$,

where x_F is the Feynman variable for D^*-meson; $z_\gamma > 0.2$, where z_γ is the fraction of photon momentum carried out by D^*-meson.

Fig. 3 presents the cross sections for D^{*+} and D^{*-}-meson production calculated in the frame work of the perturbative recombination mechanism has been shown as well as the contribution due to photon-gluon fusion. The perturbative recombination contributes to the charge asymmetric part of the total cross section, while the photon-gluon fusion contributes to the charge symmetric one. The predictions of perturbative recombination and photon-gluon fusion for D^{*0} and $\bar{D}^{*0}$-meson production are presented in Fig. 4.

In the kinematical region under consideration the perturbative recombination dominates due to a valence quark of the initial proton, as it is seen in Fig. 3 and 4. On the face of it, it seems that $\sigma(D^-) \ll \sigma(D^+)$ and $\sigma(D^0) \ll \sigma(\bar{D}^0)$. However, it is worth to note that $D^-(\bar{D}^0)$-meson in the perturbative recombination is produced in association with the c-quark (see Fig. 5 and 6). To estimate the charge asymmetry value resulted from from a pertubative recombination one needs to keep in mind that c-quark also produces the charm particles. Let us suppose, that c-quark hadronizes into final states with probabilities W_{D^*} $(c \to D^*)$, W_D $(c \to D)$, W_{D_s} $(c \to D_s)$ and W_{Λ_c} $(c \to \Lambda_c)$ (each do not necessarily equal to the appropriate probabilities at large c-quark momenta). To calculate the contribution of c-quark factorization process into the cross section one needs to take into account only particles, which are produced by c-quark in the kinematical region of COMPASS experiment.

To explain the assertion stated above, let us consider an example. To estimate the yield of the D^{*-}-meson produced in the recombination process, $\gamma d \to D^{*-}(\bar{c}d) + c$, we apply the following cuts $x_F(D^{*-}) > 0.2$, $z_\gamma(D^{*-}) > 0.2$ and do not care about c-quark. To estimate the contribution of the remained c-quark, then we apply the cuts on $x_F > 0.2$ and $z_\gamma > 0.2$ for the product of c-quark hardronization and do not care about $D^{*-}(\bar{c}d)$-meson.

Since an interaction energy is closed to threshould one, it is reasonable to suppose that the total momentum of c-quark carried out by the charm meson. However, one can not exclude that the charm meson carries out only a part of the c-quark momentum, as it takes place at high interaction energies. That is why we consider two extreme cases:

1. the total momentum of c-quark is passed to meson;

2. An energy loss of c-quark is described by Kartvelishvili fragmentation function [11]:

$$f(z) \sim z_D^{2.2}(1 - z_D) \tag{10}$$

The charge asymmetry of D^{*-}-meson production is described by the equation:

$$A^{D^{*+}} = \frac{\sigma^{D^{*+}}_{\text{total}} - \sigma^{D^{*-}}_{\text{total}}}{\sigma^{D^{*+}}_{\text{total}} + \sigma^{D^{*-}}_{\text{total}}}. \tag{11}$$

Let us $\sigma^{D}_{\gamma g}$ be the cross section value for meson production in the photon-gluon fusion; $\sigma^{D}_{\gamma q}$ is the cross section value of meson production in the perturbative recombination with light quark q; while $\sigma^{c}_{\gamma q}$ is the cross section value of the "nonrecombinated" c-quark production. Using these notations the asymmetry has the form as follows:

$$A^{D^{*+}} = \frac{(\sigma^{D^{*+}}_{\gamma \bar{d}} - \sigma^{D^{*-}}_{\gamma d}) - W_{D^*}(\sigma^{\bar{c}}_{\gamma \bar{d}} - \sigma^{c}_{\gamma d} + \sigma^{\bar{c}}_{\gamma \bar{u}} - \sigma^{c}_{\gamma u})}{(\sigma^{D^{*+}}_{\gamma \bar{d}} + \sigma^{D^{*-}}_{\gamma d}) + W_{D^*}(\sigma^{\bar{c}}_{\gamma \bar{d}} + \sigma^{c}_{\gamma d} + \sigma^{\bar{c}}_{\gamma \bar{u}} + \sigma^{c}_{\gamma u}) + 2\sigma^{D^{*+}}_{\gamma g}}. \tag{12}$$

For the case (1) when the meson carries out the whole c-quark momentum our calculation leads to the following result:

$$A_1^{D^{*+}} \simeq -0.03.$$

For the case (2) when an energy loss of c-quark is described by Kartvelishvili fragmentation function [11], one gets:

$$A_2^{D^{*+}} \simeq -0.17.$$

For the neutral meson production one has another predictions:

$$A_1^{D^{*0}} \simeq -0.08,$$

$$A_2^{D^{*0}} \simeq -0.21.$$

One can see that the asymmetry values both for neutral and charged mesons strongly depend on assumptions about the fragmentation mechanism for the "nonrecombinated" c-quark. Therefore a lack of knowledge about this mechanism does not allow to calculate asymmetry values $A^{D^{*+}}$ and $A^{D^{*0}}$ with reasonable accuracy.

Nevertheless, the more accurate prediction really exits in the considered kinematical region. In spite of the absence of s-quark inside an initial nucleon the perturbative mechanism leads to the charged asymmetry in D_s-meson production. As it mention above, the production of the mesons with $\bar{c}$-quark in the perturbative recombination occurs with an additional production of c-quark. This c-quark can hadronize into D_s^+. Therefore an additional yield of D^{*-} and $\bar{D}^{*0}$-mesons leads to an additional yield of D_s^+-mesons.

The asymmetry for D_s-meson production is described by following expression:

$$A^{D_s^+} = \frac{-W_{D_s}(\sigma^{\bar{c}}_{\gamma \bar{d}} - \sigma^{c}_{\gamma d} + \sigma^{\bar{c}}_{\gamma \bar{u}} - \sigma^{c}_{\gamma u})}{W_{D_s}(\sigma^{\bar{c}}_{\gamma \bar{d}} + \sigma^{c}_{\gamma d} + \sigma^{\bar{c}}_{\gamma \bar{u}} + \sigma^{c}_{\gamma u}) + 2\sigma^{D_s^+}_{\gamma g}}. \tag{13}$$

Our estimates are given below:

$$A_1^{D_s^+} \simeq 0.57$$

and

$$A_2^{D_s^+} \simeq 0.64$$

Thus, the perturbative recombination mechanism leads to the essential charge asymmetry in the process of D_s-meson production. The value of such asymmetry depends weakly on assumptions about the fragmentation mechanism for the "nonrecombinated" c-quark.

3. CONCLUSION

The perturbative recombination mechanism, which violates a factorization theorem in charmed hadron production causes the charge asymmetry in production of these particles. To calculate correctly the asymmetry value, ones need to take into account the hardonization of "nonrecombinated" charm (anticharm) quark, which is produced together with the anticharm (charm) quark to be recombinated with the light constituent quark of initial proton.

In the considered process of the charm photoproduction into the region of photon fragmentation the nonzero value of charge asymmetry takes place due to the backward scattering of valence quark of the initial hadron. In the discussed kinematical region the asymmetry becomes negligible with energy increasing. In the condition of COMPAS experiment the asymmetry value is small in $D^\star$-meson production, but it is essential in D_s-meson production.

Therefore one can observe an interesting phenomenon: the production of $D^{+(\star)}$ meson, which contains the light valence quark from the initial proton, leads to the charge asymmetry in the production of D_s-mesons, which does not contain the valence quark from the initial proton. In spite of small D_s meson yield, the charge asymmetry $A^{D_s^+}$ is large and it depends insignificantly on details of a fragmentation model. Note that the first time a such effect was considered in [12] where a possible asymmetry in B_s-meson production in pp-collisions was investigated. This process had been also investigated in paper [9].

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1. M. I. Adamovich *et al.* [WA82 Collaboration], Phys. Lett. B **305**, 402 (1993); G. A. Alves *et al.* [E769 Collaboration], Phys. Rev. Lett. **72**, 812 (1994); G. A. Alves *et al.* [E769 Collaboration], Phys. Rev. Lett. **77**, 2388 (1996); E. M. Aitala *et al.* [E791 Collaboration], Phys. Lett. B **371**, 157 (1996); E. M. Aitala *et al.* [E791 Collaboration], Phys. Lett. B **411**, 230 (1997); M. I. Adamovich *et al.* [WA89 Collaboration], Eur .Phys. J. C **8**, 593 (1999).
2. A. K. Likhoded, S. R. Slabospitsky, and Suslov M.V., Yad.Fiz. **38**, 727 (1983); V. G. Kartvelishvili, A. K. Likhoded, and S. R. Slabospitsky, Yad. Fiz. **32**, 236 (1980); A. K. Likhoded and S. R. Slabospitsky, Phys. Atom. Nucl. **62**, 693, (1999).
3. J. C. Anjos *et al.* [Tagged Photon Spectrometer Collaboration], Phys. Rev. Lett. **62**, 513(1989).
4. M. P. Alvarez *et al.* [NA14/2 Collaboration], Z. Phys. C **60**, 53 (1993).
5. P. L. Frabetti*et al.* [E687 Collaboration], Phys. Lett. B **370**, 222 (1996).
6. R. K. Ellis and P. Nason, Nucl.Phys. B **312**, 551 (1989); S. Frixione, M. L. Mangano, P. Nason, and G.Ridolfi, Nucl. Phys. B **412**, 225 (1994); J. Smith and W. L. van Nerven, Nucl Phys. B **374**, 36 (1992).
7. A. V. Berezhnoy, V. V. Kiselev, A. K. Likhoded, Phys. Atom. Nucl. **63**, 1595(2000); A. V. Berezhnoy, V. V. Kiselev, and A. K. Likhoded, Phys. Rev. D **62**, 074013 (2000); A. V. Berezhnoy, V. V. Kiselev, and A. K. Likhoded, Phys. Atom. Nucl. **66**, 769 (2003).
8. J. Breitweg *et al.* [ZEUS Collaboration], Eur. Phys. J. C **6**, 67, 1999.
9. E. Braaten, Yu Jia, and T. Mehen, Phys. Rev. D **66**, 014003 (2002).
10. C. Peterson *et al.*, Phys. Rev. D **27** 105 (1983).
11. V. G. Kartvelishvili, A. K. Likhoded, V. A. Petrov, Phys. Lett. B **78**, 615 (1978)
12. A. M. Zaitsev and A. A. Solodkov, Nucl. Inst. A **333**, 169 (1993).

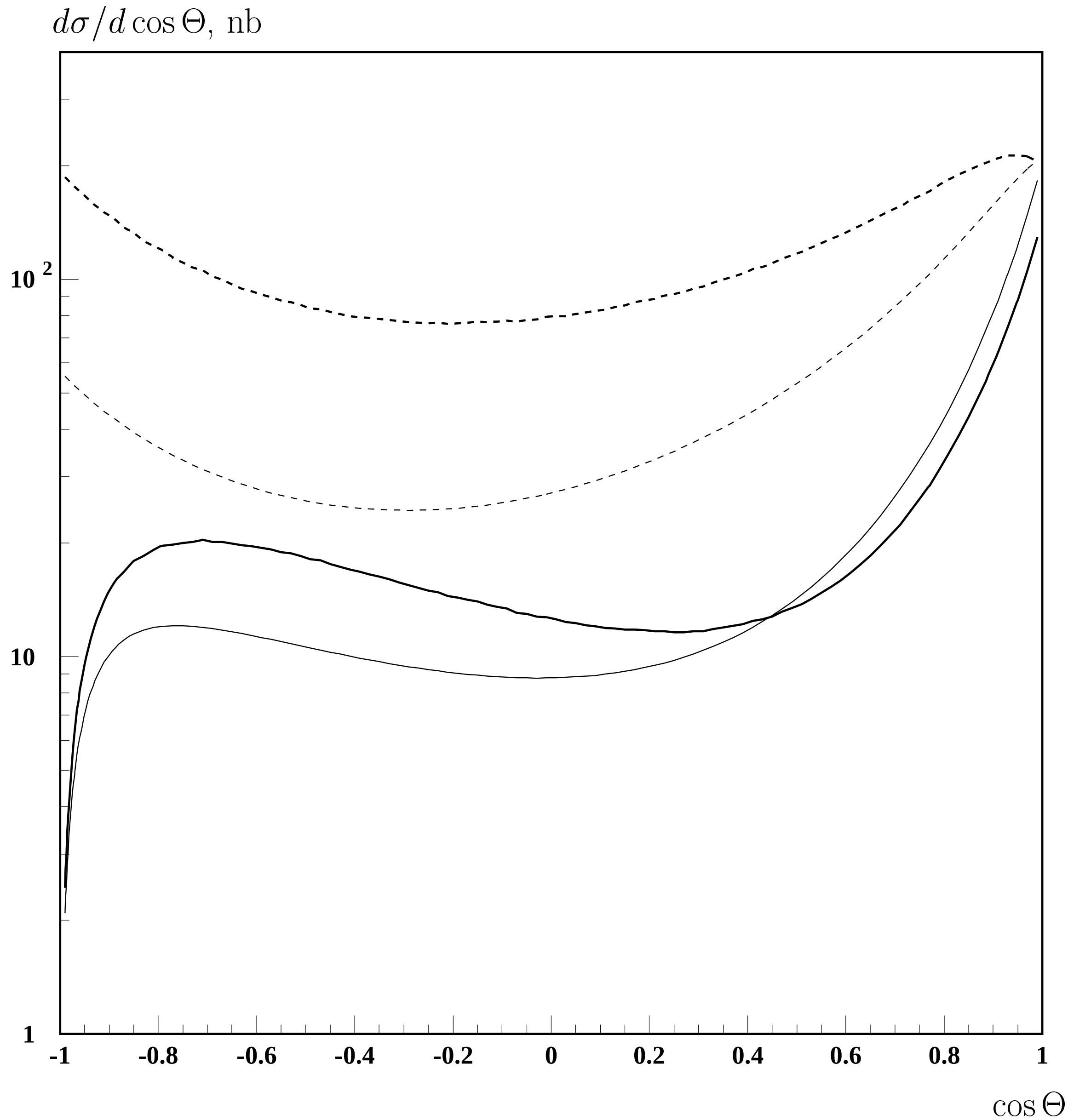

Figure 1. The cross section distributions over the scattering angle cosine of $(d\bar{c})$-meson in c.m.s. for the process $d\gamma \to (d\bar{c}) + c$ both for the vector (solid curves) and pseudoscalar (dashed curves) meson states. Ours predictions (bold curves) have been performed in comparison with the predictions of work [9] (thin curves). $\sqrt{s_{d\gamma}} = 5$ GeV, $m_c = 1.5$ GeV, $m_d = 0.3$ GeV.

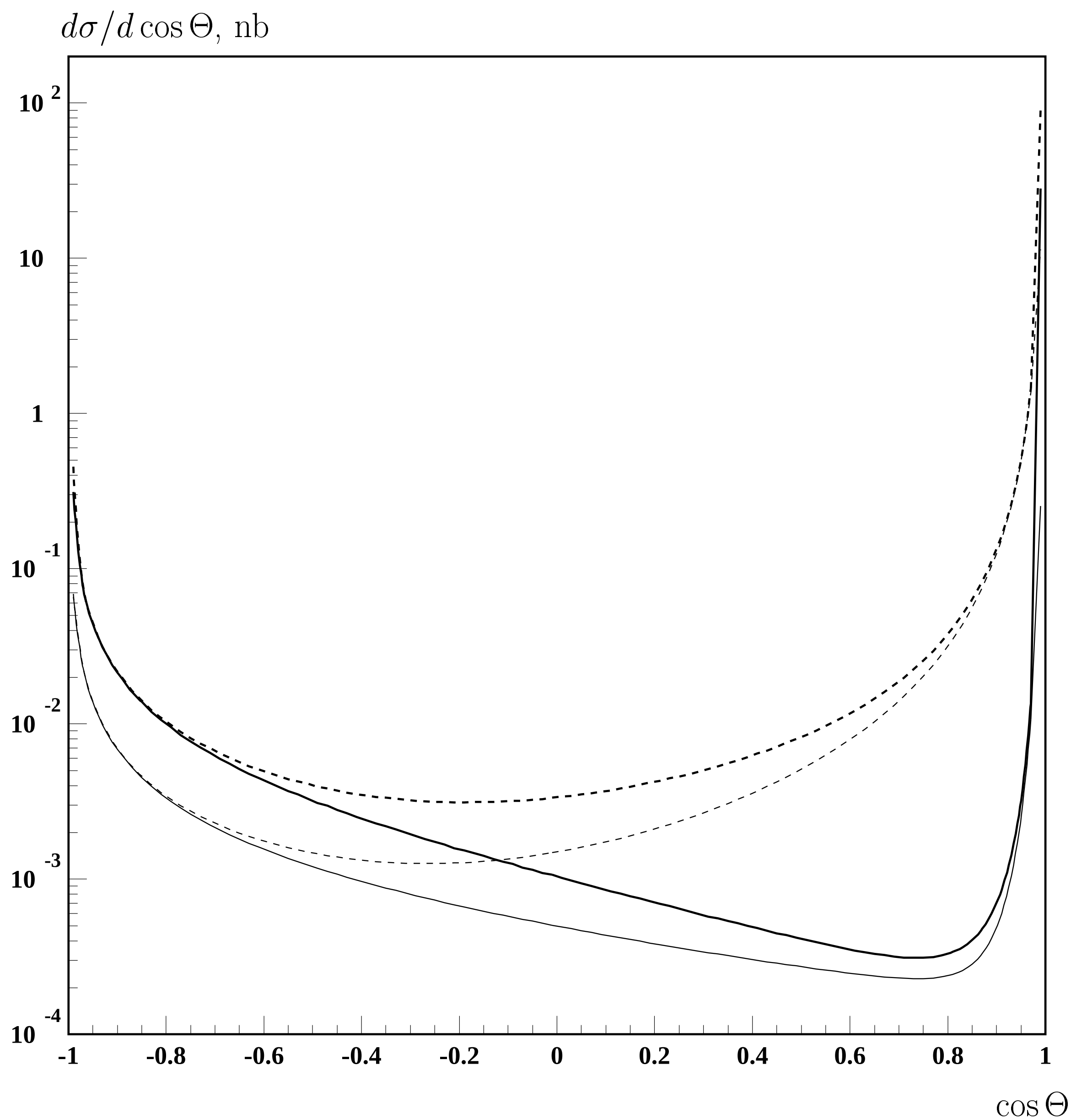

Figure 2. The same as in Fig. 1 but for $\sqrt{s_{d\gamma}} = 100$ GeV, $m_c = 1.5$ GeV, and $m_d = 0.1$ GeV.

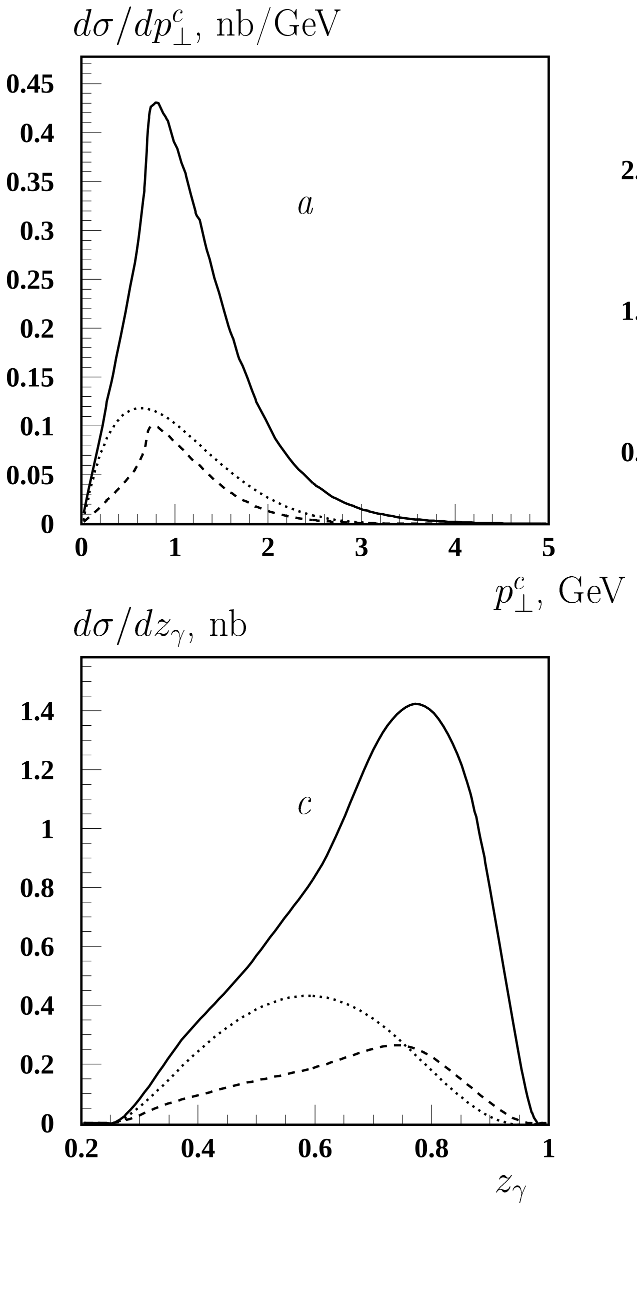

Figure 3. The cross sections as a function of $p_\perp^D$ (a), x_F (b), and z_γ (c) for the following subprocesses of charged charmed meson photoproduction: D^{*-}-meson production in the perturbative recombination process $d\gamma \to D^{*-} + c$ (solid curve); D^{*+}-meson production in the perturbative recombination process $\bar{d}\gamma \to D^{*+} + \bar{c}$ (dashed curve); the production of D^{*+} and D^{*-}-mesons in photon-gluon fusion.

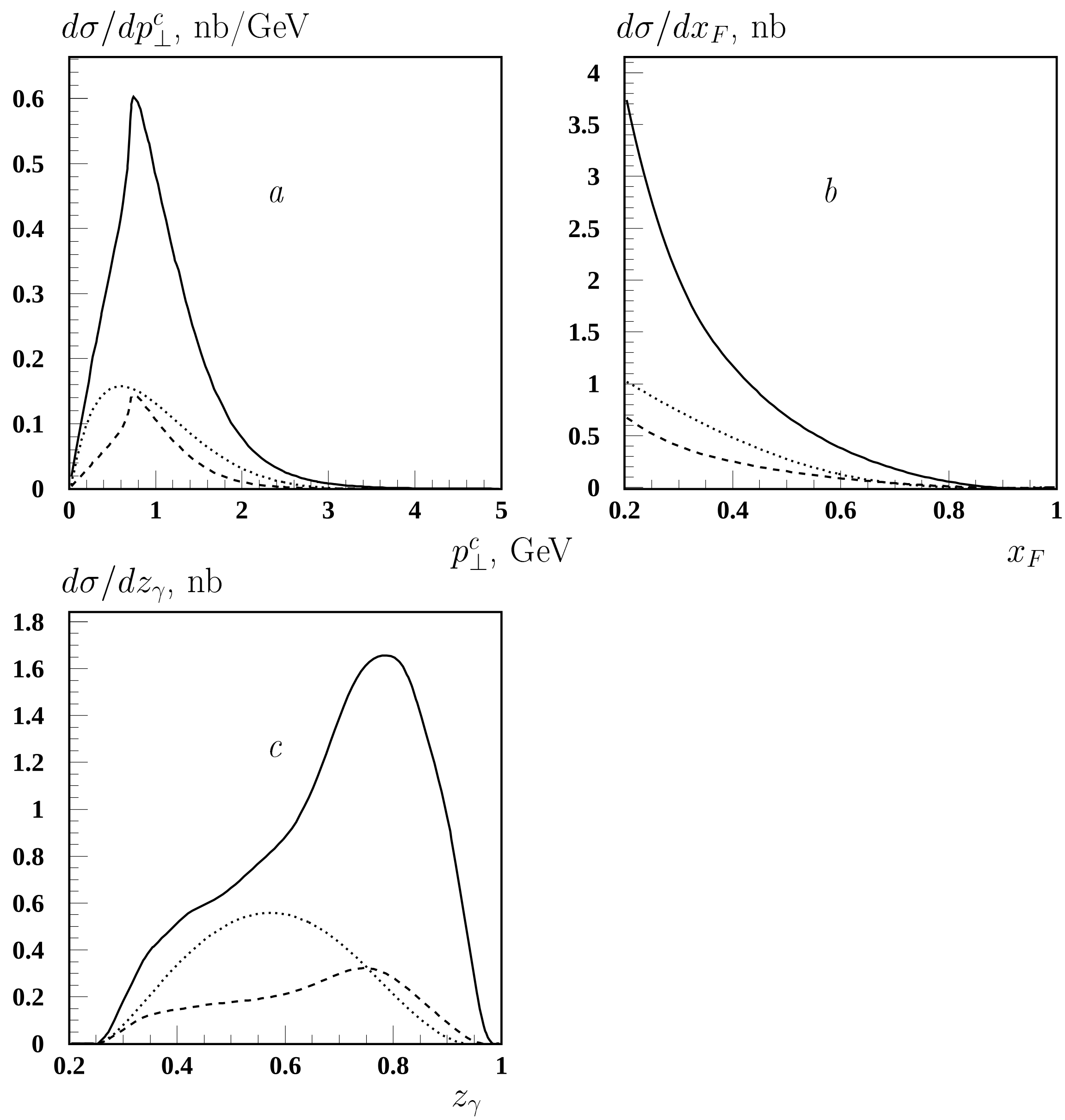

Figure 4. The cross sections as a function of $p_\perp^D$ (a), x_F (b), and z_γ (c) for the following subprocesses of neutral charmed meson photoproduction: $\bar{D}^{*0}$-meson production in the perturbative recombination process $u\gamma \to \bar{D}^{*0} + c$ (solid curve); D^{*0}-meson production in the perturbative recombination process $\bar{u}\gamma \to D^{*0} + \bar{c}$ (dashed curve); the production of D^{*0} and $\bar{D}^{*0}$-mesons in photon-gluon fusion.

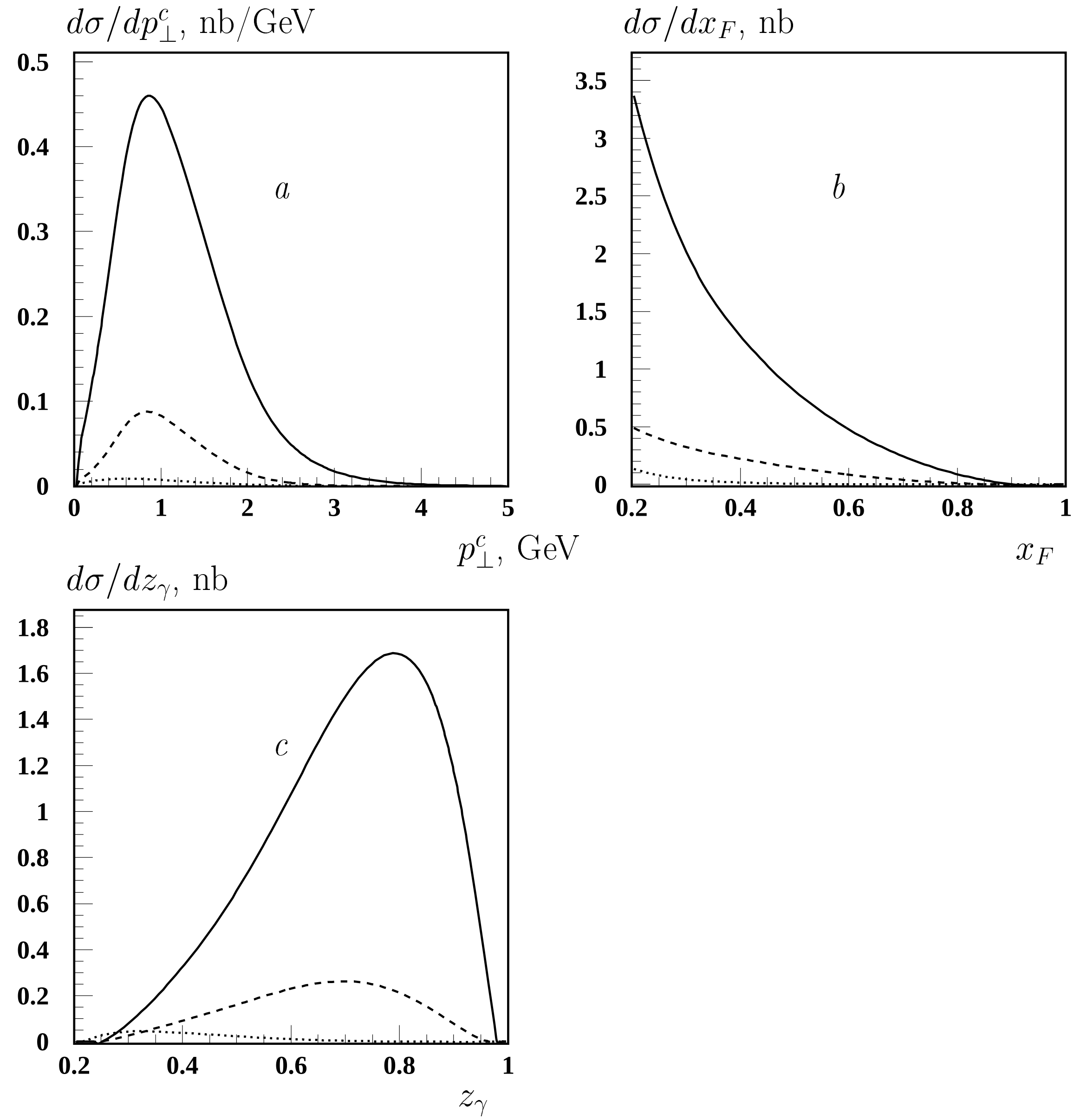

Figure 5. The cross sections as a function of the kinematic variables of "nonrecombinated" charm quark $p_\perp^c$ (a), x_F^c (b), and z_γ^c (c) for the following subprocesses of charged charmed meson photoproduction: D^{*-}-meson production in the perturbative recombination process $d\gamma \rightarrow D^{*-} + c$ (solid curve); D^{*+}-meson production in the perturbative recombination process $\bar{d}\gamma \rightarrow D^{*+} + \bar{c}$(dashed curve); the production of D^{*+} and D^{*-}-mesons in photon-gluon fusion.

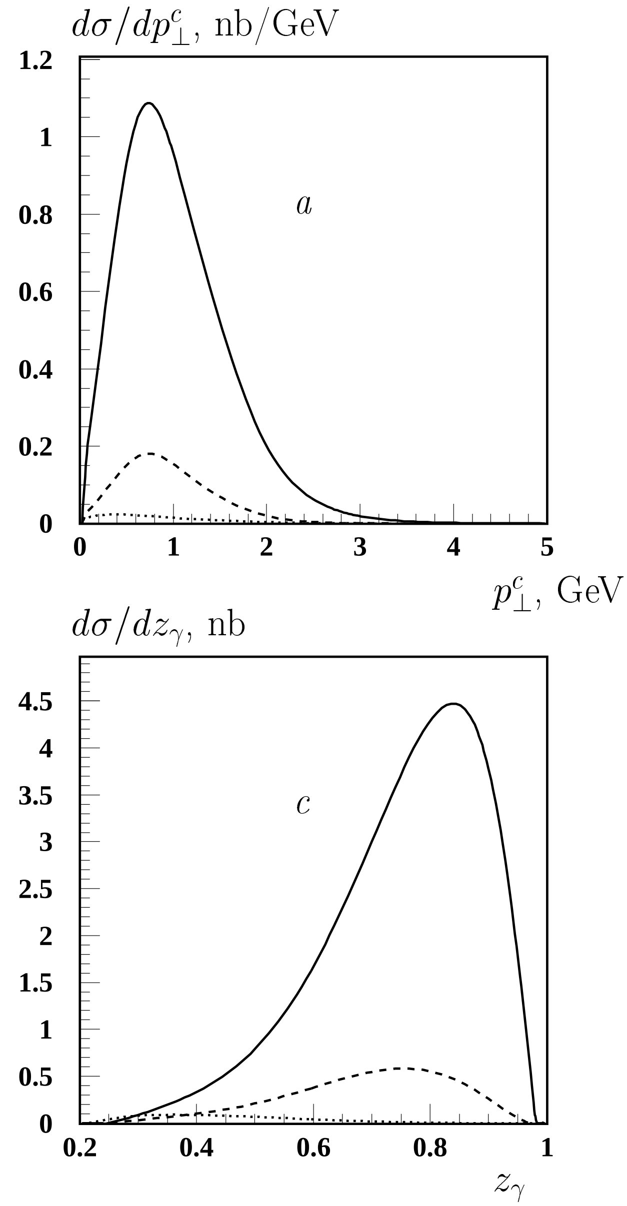

Figure 6. The cross sections as a function of the kinematic variables of "nonrecombinated" charm quark $p_\perp^c$ (a), x_F^c (b), and z_γ^c (c) for the following subprocesses of neutral charmed meson photoproduction: $\bar{D}^{*0}$-meson production in the perturbative recombination process $u\gamma \to \bar{D}^{*0} + c$ (solid curve); D^{*0}-meson production in the perturbative recombination process $\bar{u}\gamma \to D^{*0} + \bar{c}$ (dashed curve); the production of D^{*0} and $\bar{D}^{*0}$-mesons in photon-gluon fusion.